Noisy Reference Effects on Multiple-Antenna Reception

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Multiple-Antenna Reception (MAR) is a technique for coherently adding the spacecraft signals received at two or more antennas in order to achieve an improvement in down-link telemetry performance. The feasibility was recently demonstrated at the second Mercury Encounter of Mariner 10. The data rate for this demonstration was a lusty 117 kbps uncoded. At this data rate, the received carrier signal is strong enough at each of the receiving sites that there is negligible loss due to noise in the carrier–tracking loops. The MAR technique could also be used to enhance the data return from the outer planet Pioneer and Mariner probes, in which case the data rates are, or can become, low enough that the effects of the noisy carrier references cannot be ignored. In the work which follows, previously developed tools for analyzing the effects of noisy carrier reference losses in the standard Deep Space Network configuration are applied to the MAR technique.

Multiple-Antenna Reception (MAR) is a technique for coherently adding the spacecraft signals received at two or more antennas in order to achieve an improvement in down-link telemetry performance. The feasibility was recently demonstrated by Wilck, et al. (Ref. 1) at the second Mercury Encounter of Mariner 10. The data rate for this demonstration was a lusty 117 kbps uncoded. At this data rate, the received carrier signal is strong enough at each of the receiving sites that there is negligible loss due to noise in the carrier–tracking loops. The MAR technique could also be used to enhance the data return from the outer planet Pioneer and Mariner probes, in which case the data rates are, or can become, low enough that the effects of the noisy carrier references cannot be ignored. In the work which follows, previously developed tools for analyzing the effects of noisy carrier reference losses in the standard Deep Space Network configuration are applied to the MAR technique.

Figure 1 is a block diagram of the MAR technique. The spacecraft signal plus Additive White Gaussian Noise is received at each of two or more receiving systems. The additive noise can be assumed to be independent at each of the receiving sites. The received carrier is phase-and-frequency tracked at each of the receiving sites, and the resulting reconstructed carrier reference is used to demodulate the telemetry sidebands from the received signal. The resulting baseband telemetry signals are combined in a weighted average depending upon their relative average SNRs; and the telemetry data stream is then detected/decoded from this combined baseband telemetry signal. The signals from each antenna are aligned in time and add coherently. The independent additive noises from each receiver add incoherently, or in mean square. The carrier phase reference noises at each antenna/receiver are also independent. We cannot, however, conveniently add these phase noises in their effect upon the detection error rate. For single-antenna reception, the effects of the carrier reference errors are included by computing the error probability as conditioned upon some value of carrier reference efficiency (losses), and then averaging over the distribution of that efficiency. Specifically, if we let η be the coherent demodulator efficiency, and $p(\eta)$ its distribution,

$$P_e = \int_0^1 \Pr\{\text{Error} \mid \text{SNR}, \eta\}\, p(\eta)\, d\eta \tag{1}$$

The form of this probability integral has been previously computed for both uncoded and convolutionally encoded–sequentially decoded telemetry (Refs. 2 and 3). This procedure can be readily utilized for the MAR situation by replacing η in Eq. (1) with the weighted average of the detection efficiencies of the individual receivers, and averaging over the distribution of the individual efficiencies. For two antennas,

$$P'_e = \int_0^1 \int \Pr\{\text{Error} \mid \text{SNR}^c, g_1\eta_1 + g_2\eta_2\}\, P(\eta_1)\, P(\eta_2)\, d\eta_1 d\eta_2 \tag{2}$$

SNR^c is the combined effective SNR; η_1, η_2 are the two instantaneous efficiencies; and g_1, g_2 are the combining weights for the two receiving systems ($g_1 + g_2 = 1$).

Figures 2a through 2c show the computed bit error probability for the MAR operation of two identical receiving antennas in comparison with the performance of a single antenna/receiver for data rates of 8, 128, and 2048 bps. The data are shown as a function of down-link modulation index for several values of the total power-to-noise spectral–density ratio. The performance shows the expected 3 dB advantage of the MAR at low modulation indices where it is determined largely by the combined SNR without consideration of the carrier reference detection efficiency. As is evidenced by Fig. 2, at extremely high modulation indices where the carrier reference efficiency is a dominant factor, there is almost no improvement in the MAR performance as compared to the individual antenna/receiver's performance. At reasonable modulation indices, the degradation due to carrier detection efficiency for uncoded telemetry from the potential 3 dB improvement of MAR is less than 0.1 dB for 2048 bps (or higher), about 0.3 dB for 128 bps, and almost 1 dB for 8 bps.

The same set of calculations has been performed for the sequential decoding deletion probability using a medium rate model (Ref. 3). The results appear as shown in Figs. 3a through 3c. At reasonable modulation indices, the degradation due to carrier detection efficiency from the potential 3 dB improvement of MAR is again less than 0.1 dB at 2048 bps, about 0.3 dB at 128 bps, and almost 1 dB at 8 bps.

References

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2. Layland, J. W., "A Note on Noisy Reference Detection," in *The Deep Space Network Progress Report*, Technical Report 32-1526, Vol. XVII, pp. 83–88, Jet Propulsion Laboratory, Pasadena, Calif., Oct. 15, 1973.
3. Layland, J. W., "A Sequential Decoding Medium Rate Performance Model," in *The Deep Space Network Progress Report*, Technical Report 32-1526, Vol. XVIII, pp. 29–33, Jet Propulsion Laboratory, Pasadena, Calif., Dec. 15, 1973.

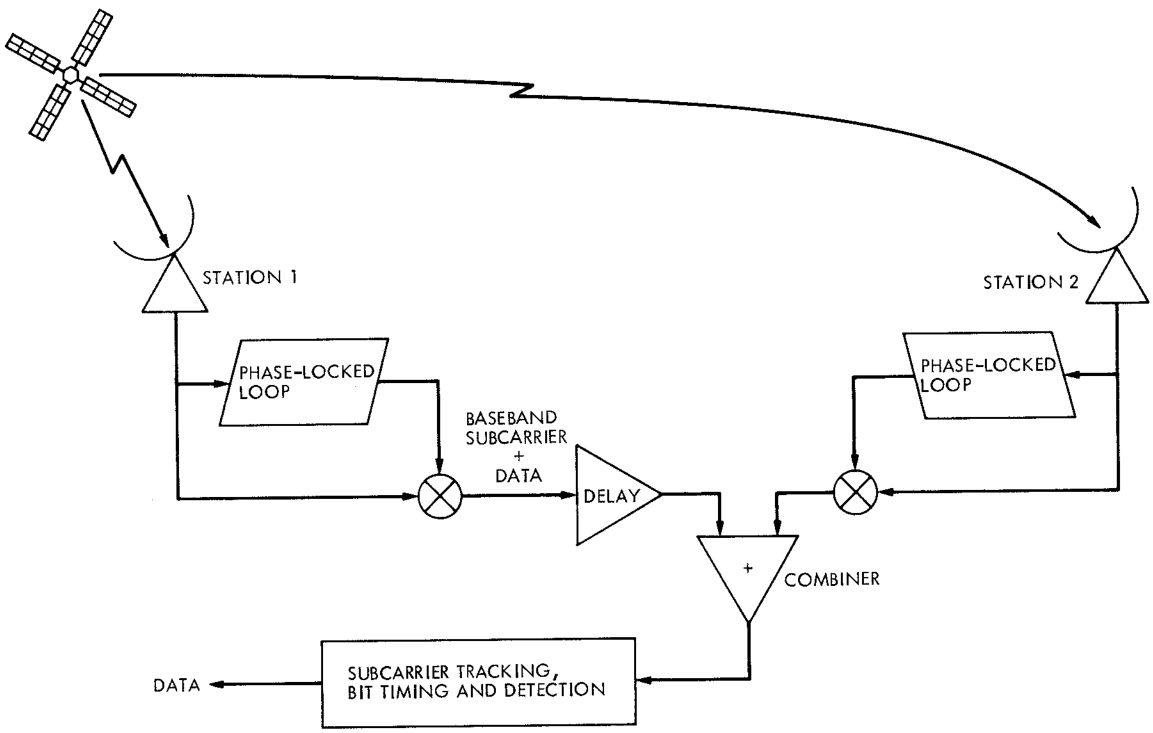

Fig. 1. Block diagram of MAR configuration

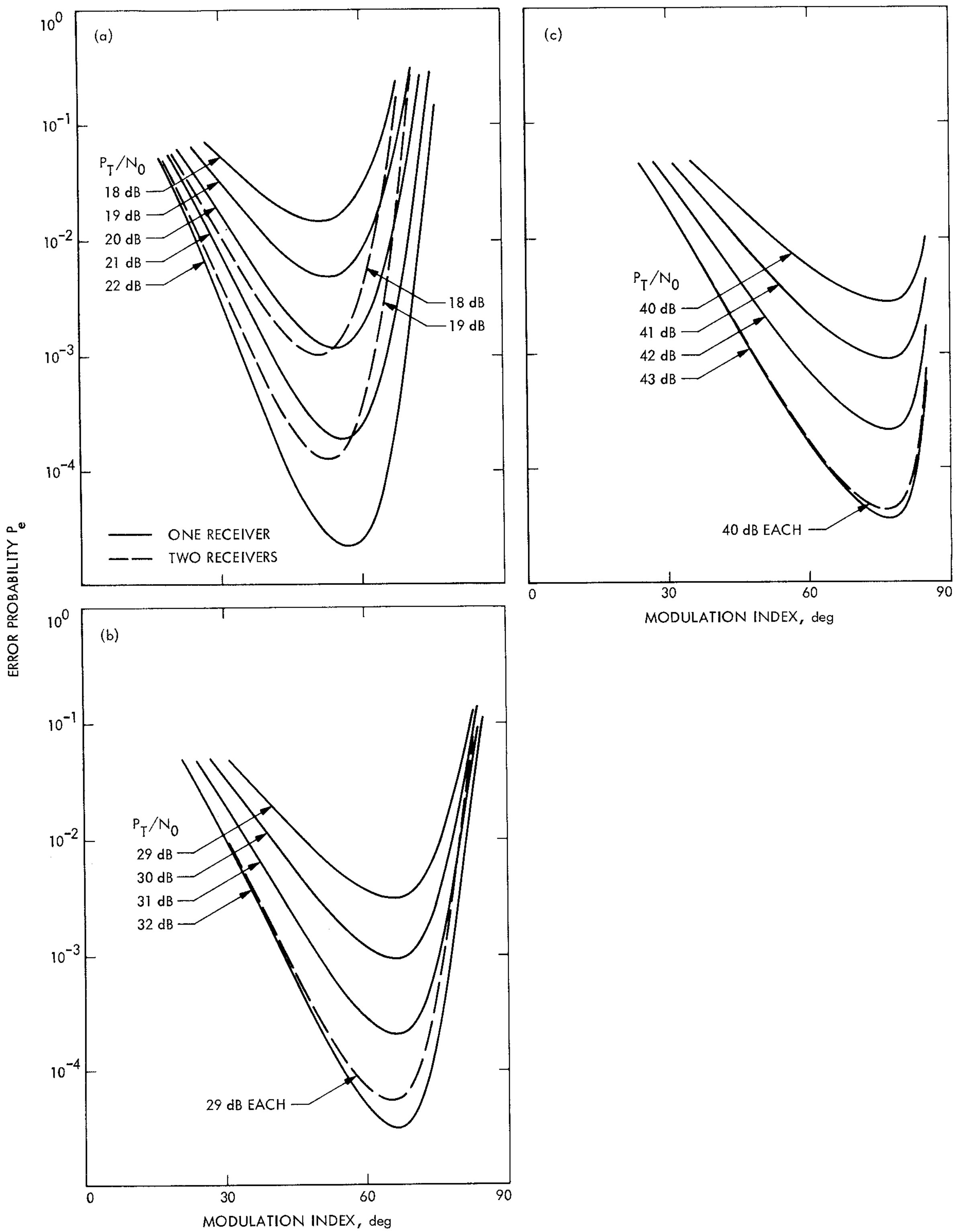

Fig. 2. Uncoded MAR performance estimate; (a) 8 bps, (b) 128 bps, (c) 2048 bps

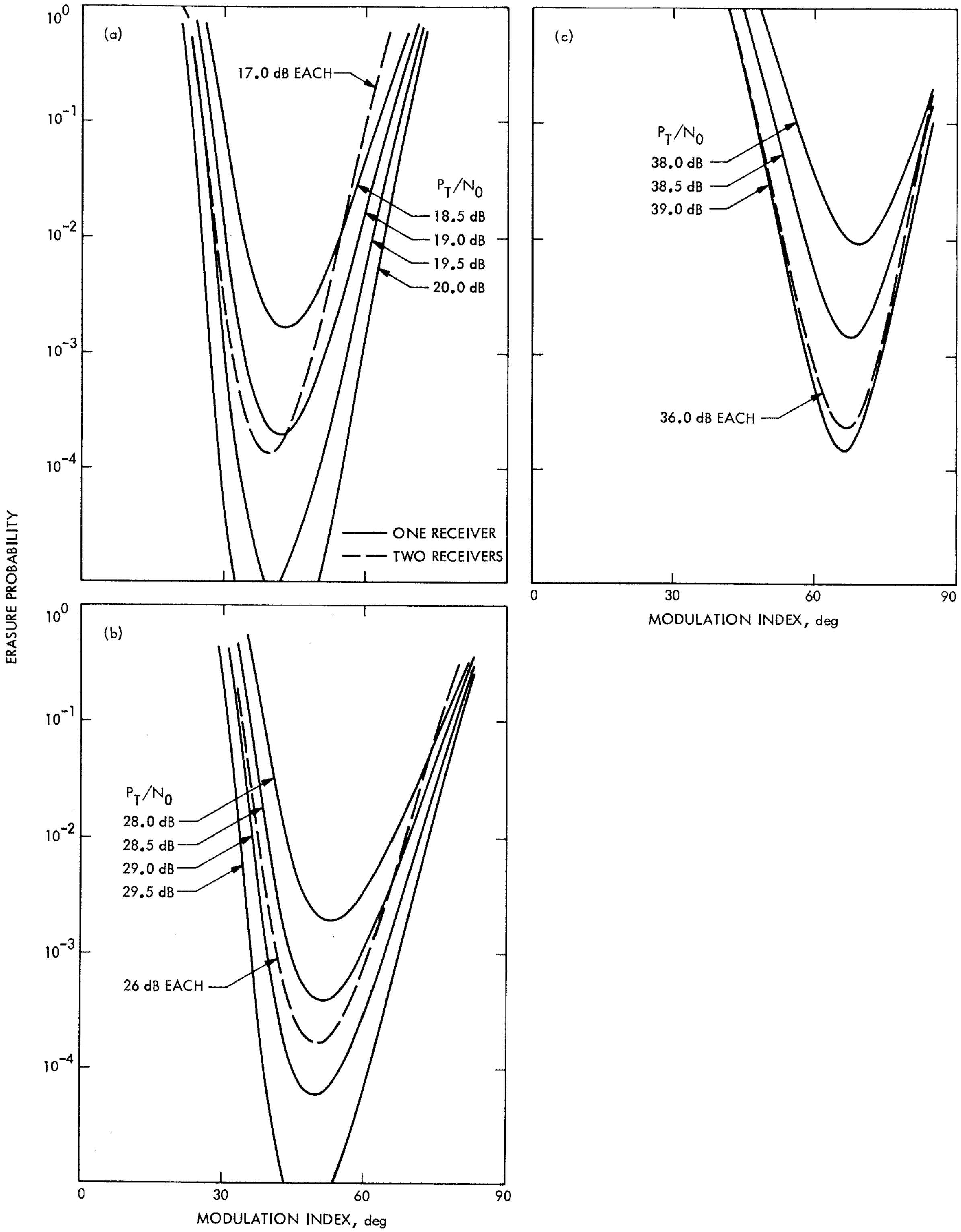

Fig. 3. Sequential decoding MAR performance estimate; (a) 8 bps, (b) 128 bps, (c) 2048 bps